Effect of The Screw-Barrel Clearance and The Cooling Fan on Non-Wheat Noodle Extruder Performance

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Abstract. This research was related to the development of technology for making non-wheat noodles. The process of making non-wheat noodles requires special treatment because of their different characteristics from wheat noodles. One solution that can be used is extrusion technology. Therefore, a single-screw extruder with a small capacity was developed which is expected to meet the needs of SMEs producing non-wheat noodles. This technology is supposed to be capable of supporting an industry based on the utilization of local raw materials, hence enhancing economic growth and sustainable development. Extruder design parameters should be adapted to the dough characteristics; thus, an experimental investigation was done to determine the appropriate design. The first design extruder needed fixing. Dough backflow occurred during the extrusion process, resulting in blocked dough feeding. The wide clearance between the screw and the barrel caused the dough to backflow. Because of friction in the process, a poorly controlled working temperature raised the temperature continually. The poorly controlled working temperature caused an overheated and puffed product. The second design extruder had the clearance smaller, with the size of 0.5 mm, had the die equipped with a breaker plate, and complemented with the cooling fan. The experimental investigation included extruder performance in throughput, energy consumption, operating temperature stability, and noodle quality at various screw rotational speeds. The screw rotational speed was set by setting the inverter at the operation frequency, which resulted in the screw rotational speed of 30 and 40 rpm. The optimum screw rotational speed was resulting the highest noodles throughput with the specific energy consumption (SEC) lower than the other screw rotational speed. The result indicated that the smaller screw-barrel clearance could minimize the backflow, and the cooling fan could maintain the working temperature, so the product puffing could be prevented, and noodle quality was better, but the specific energy consumption was higher than the previous one. Keywords: Extrusion Technology, Non-Wheat Noodles, Extruder Design, Dough Characteristics, Sustainable Development

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1 Introduction

Sustainable development can be held by optimizing the potential of local resources, both natural resources and mastery of technology by human resources, including the development of food security. One of the food products that many people like is noodles. Generally, noodles are produced using wheat flour. But in Indonesia, wheat is a raw material that cannot be produced domestically. On the other hand, Indonesia has various commodities that can be used to make noodles. Some researchers have made non-wheat noodles from flour mixtures ([1], [2], and [3]). However, making noodles from non-wheat ingredients requires a different technology to produce noodles that are almost the same as wheat noodle products, one of them is extrusion technology.

Extrusion technique has been widely used in food industry production due to some advantages. The advantages of this technique are high productivity, various product shapes, and very economical process technology for producing a new product ([4], [5], and [6]). Non-wheat noodles have characteristics that differ from wheat noodles, so they must be treated differently during production. Several types of research have been conducted to make noodles from non-wheat material. Other researcher [7] reported the methods to make corn noodles such as calendaring, extrusion, and calendaring-extrusion combination. In another work, [8] utilized a small capacity plastic extruder of Scientific Laboratory Single Screw Extruder type LE25-30/C from Labtech Engineering Co. Ltd. Thailand with the capacity of 3 kg/h for producing corn noodles. In the other work [9], they used extrusion-cooking process to produce corn-broad bean spaghetti-type pasta.

One of the drawbacks of the extrusion process is the high demand for energy. The energy is used to operate the motor drive, cooling system, heater, and electronic components. The highest energy consumption is used to run the motor drive [10]. It might be due to a combination of a process such as mixing, kneading, heating, etc., occurred inside the screw-barrel component.

This paper aimed to investigate two designed non-wheat noodles extruders. The first design had a wider screw-barrel clearance and lacked a cooling fan. The second extruder design had narrower screw-barrel clearance and had equipped with a cooling fan. The second design was an improvement of the first design. The first design had drawbacks, namely the occurrence of backflow of dough and temperature spiked during the process. Experimental studies observed the effect of different screw-barrel clearances on extruder performance in throughput and energy consumption at screw rotational speeds set at 30 and 40 rpm and the effect of the addition of a cooling fan on the stability of the operating temperature.

2 Materials and methods

All experiments were conducted on the first and second designs of single-screw extruders. Figure 1 shows schematic representations of the single screw extruder that had been used in this research.

The first design extruder has a screw and barrel clearance of 1.15 mm, and the driver is an electrical motor at a speed of 1500 rpm, with ratings: 220VAC and power of 3 Hp (2,2 kW). A fixed gearbox connects the screw and the driving motor with a 30:1 ratio. The barrel has a temperature zone with a heater of 1 kW. The heater is equipped with a temperature controller, which allows control of the set temperature. The barrel has a temperature zone with a heater of 1 kW and is equipped with a temperature controller, which allows control of the set temperature. The inverter controlled the screw rotation
speed to set the experimental speed. The inverter frequency was set at 30 and 40 Hz with the screw rotation speed at 30 and 40 rpm.

The second design extruder has the screw and barrel clearance of 0.5 mm, the driver is an electrical motor at a speed of 1440 rpm, with ratings: 220VAC, 5 hp (3.77 kW). A fixed gearbox connects the screw and the driving motor with a 40:1 ratio. The barrel has a temperature zone with a heater of 1 kW and a cooling fan of 150 W. The heater and cooling fan are equipped with a temperature controller, which allows control of the set temperature. Screw rotation speed was controlled by the inverter to set the experimental speed. The inverter frequency was set on at 40.7 Hz and 54.7 Hz with the screw rotation speed at 30 rpm and 40 rpm.

Barrel temperature was set on 75°C. Screw motor drive was turned on after the barrel temperature reached the set temperature. The dough was pouring into the hopper to entering the barrel. The logged data are time, barrel temperature, dough temperature, and current of the electrical motor. Output noodle from the die was cut and weighed every 30 seconds. Throughput, noodles output from the extruder at a time period, was calculated using the equation (1). Recording data were carried out until the last extruded noodle.

\[
\text{throughput (grams/second)} = \frac{\text{mass of noodle (gram)}}{\text{time interval (second)}}
\]

(1)

The analog stopwatch was used to measure the time interval. The K-type thermocouple is mounted on the outer surface of the barrel to measure the set and process temperatures. The infrared temperature was used to measure the dough temperature. The current was measured by clamp ampere. Extruded noodles were weighted by digital balance.

Fig. 1. Schematics diagram of non-wheat noodles single screw extruder

Specific energy consumption (SEC) was defined as the calculated energy from current data divided by throughput over a stable throughput period. The SEC is calculated as below:

\[
\text{SEC (kJ/kg)} = \frac{P \text{(kJ/s)}}{\text{Throughput (kg/s)}}
\]

(2)

Where the P is power or energy rate consumption, it can be measured by measuring the electrical current (I, ampere) and the voltage (V, volt) of the machine during the operation.
The experiment conducted with dough of flours mixture with the composition of modified cassava flour, rice flour, corn flour, tempeh flour, water, and salt. All the ingredients were mixed using the dough mixer. Furthermore, the dough was steamed and extruded. Steaming and extruder feeding process was carried out in stages per one kg of base material in accordance to steaming capacity.

The data collected during the extrusion process were substituted into equations (1), (2), and (3) to calculate the throughput and SEC, the throughput value of each time interval was plotted on the throughput chart. throughput and SEC of extruder were determined based on the average throughput and SEC values at stable extrusion conditions, excluding at the beginning and end of the process. The temperature data were plot to the temperature profile chart.

3 Equations and mathematics

3.1 Effect of the screw-barrel clearance on non-wheat noodles extruders performance

Some of extruder performance indicators are throughput of product and specific energy consumption. Throughput indicates the working capacity of the extruder. Specific energy consumption indicates how much energy is used for making the product.

Figure 2 shows a throughput during the process using the first design extruder. Figure 2 (a) shows the noodles throughput during the process at the rotational speed of the screw was 30 rpm. The initial throughput was low. Furthermore, the throughput increased slowly until reached stable output between the time of 1110 s and 2310 s with an average throughput of 1.36 g/s or 4.9 kg/hour. Similarly, in figure 2 (b), the throughput initially low and increased linearly until reached stable condition at the time of 690 s. The stable throughput condition occurred from the time of 690 s to 1860 s. The average throughput at the stable condition was 1.7 g/s or 6.2 kg/hour.

Figure 3 shows a throughput during the process using the second design extruder. The initial throughput was low. Furthermore, the throughput increased slowly until reached stable output between the time of 570 s and 1800 s with an average throughput of 1.2 g/s or 4.3 kg/hour. The throughput decreased at the rest of the process. The process indicates the throughput at 30 rpm is.

Similarly, in figure 3 (b), the stable throughput condition occurred from the time of 600 s to 1260 s. The average throughput at the stable condition was 1.7 g/s or 6.2 kg/hour. From the graph, it can be concluded that the output of the noodles for screw rotation of 40 rpm is 1.44 grams/second or 5.2 kg/hour.

\[
\text{Throughput} = \omega(V)(t)
\]

\[
P \text{ (kJ/s)} = \omega(V)(t)
\]
Fig. 2. Extruder throughputs from the first design extruder at each screw rotation speed. (a) 30 rpm. (b) 40 rpm

Figure 3 shows a throughput during the process using the second design extruder. The initial throughput was low. Furthermore, the throughput increased slowly until reached stable output between the time of 570 s and 1800 s with an average throughput of 1.2 g/s or 4.3 kg/hour. The throughput decreased at the rest of the process. The process indicates the throughput at 30 rpm is. Similarly, in figure 3 (b), the stable throughput condition occurred from the time of 600 s to 1260 s. The average throughput at the stable condition was 1.7 g/s or 6.2 kg/hour.

Fig. 3. Extruder throughputs from the second design extruder at each screw rotation speed. (a) 30 rpm. (b) 40 rpm
Noodles throughput increased along with the increased of screw speed rotation because the mass flow rate of the dough was also getting faster. The higher the screw speed rotation, the higher the noodles throughput. The first design extruder has a throughput of 4.9 kg/hour at a screw rotational speed of 30 rpm and increased to 5.2 kg/hour at 40 rpm. The second design extruder has a throughput of 4.3 kg/hour at a screw rotational speed of 30 rpm and increased to 6.2 kg/hour at 40 rpm. The comparison of both design throughput shown in the figure 4. The first design with wider screw-barrel clearance had higher throughput at the low speed (30 rpm). However, at higher speed, the second design with narrower screw-barrel clearance had better performance with higher throughput. It caused the first design extruder had more backflow of dough at high-speed rotation. At the high screw rotational speed, the melt pressure in the extruder is also higher [11]. This higher pressure caused more backflow of dough.

![Fig. 4. Throughput of two design non-wheat extruders at varies screw rotational speed](image)

The first design extruder has an SEC of 646.6 kJ/kg at 30 rpm of the screw rotational speed and increases to 785.1 kJ/kg at 40 rpm of the screw rotational speed. For the second design extruder, the SEC at 30 rpm is very high compared to 40 RPM screw rotation, with lower throughput. It means the second design extruder was unsuitable for low-speed operation, and it had optimum operation conditions at 40 rpm screw rotation with SEC 893.2 kJ/kg and throughput of 6.2 kg/hour. The comparison of both design extruders SEC is shown in figure 5.

![Fig. 5. Specific energy consumption (SEC) of two design non-wheat extruder at varies screw rotational speed](image)
Fig. 5. Specific energy consumption (SEC) of two design non-wheat extruder at varies screw rotational speed.

In the second design extruder, it has a narrow screw-barrel clearance, no backflow of dough occurred, and all the dough in the extruder was pushed toward the die and could only come out through the small hole in the die. This caused needing of the high energy to extrude the dough. At slow screw rotation, the pressure inside the extruder is also smaller, so the throughput was small. The small throughput and high energy gave the higher value of SEC if the second design extruder operated at low speed.

Previous research [12] stated that the extruder usually has an excessive power consumption if the extruder motor SEC is above 0.3288 kW h/kg or 1183 kJ/kg. Therefore, according to that work, the SEC values in this experiment indicate that there was no excessive power consumption in the extruder.

3.2 Effect of the cooling fan on extruder temperature and

The barrel temperatures during the extrusion process using the first design extruder are shown in figure 6 (a) and 6 (b) for screw rotational speeds of 30 and 40, respectively. The barrel temperature was set at 60°C but tends to increase during the process. This extruder was not equipped with the cooling fan. The friction between the dough, the screw element, and the barrel caused this increased temperature. This result is consistent with the research conducted by the other researcher [13]. The other research [14] reported that the heat generated by mechanical work increases with the screw speed.

The initial dough temperatures at the hopper were around 55°C to 75°C, at the end of the process temperature decreased by about 35°C because the dough was in direct contact with the air of the environment. Figure 6 (a) shows the dough temperature at the screw speed of 30 rpm. The dough temperature reached 67 °C at the time of 17 minutes due to feeding process was carried out in 2 batches in which the dough temperature from steamer still high. The trend of this dough temperature was also occurred at the screw speed of 40 rpm, as shown in figure 3(b).
The dough temperature affected the increase of barrel temperature. However, heat from the heater and mechanical work friction affected the barrel temperature greater. Figure 6 shows the barrel temperature initially decreased as the effect of the dough temperature. Furthermore, the barrel temperature increased slowly when the heater and friction take a role. When the dough had run out, the barrel temperature had increased again. This trend proves that the friction has the higher effect on the barrel temperature. The continuous increase in temperature during the process until it reached above 80°C caused the extrudate noodles to puff and become rejected products.

The second design extruder had been equipped with a heater and cooler to maintain the barrel temperature. Figure 7 shows that the barrel temperature is relatively stable at only a few higher than the set point of 75°C, hence the extruded noodles were not puffed.
Fig. 7. Barrel and dough temperatures at the second design extruder at varies screw rotational speed. (a) 30 rpm (b) 40 rpm

4 Conclusions

The results indicate that the second design extruder with the screw-barrel clearance of 0.5 mm can minimize the dough backflow that occurred at the first design extruder. The second design extruder also has maximum throughput higher than the first one. The second design equipped with a cooling fan could control the working temperature better than the first one, therefore it prevented the extruded noodles puff. Otherwise, the specific energy consumption of the second design is higher than the first design extruder.

The Ministry of Research and High Education Republic of Indonesia supported this project through the INSINAS Project year 2019 under grant number 15/INS-1/PPK/E4/2019 on February 25, 2019.

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